Lattice Girder Elements – Structural Behaviour and Performance Enhancements

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ABSTRACT

A study was made of the structural behaviour of lattice girder elements. The purpose of this study was to gain knowledge of the structural behaviour, identify possible performance enhancements made possible by the use of new material technology. Through a deep understanding of the structural behaviour coupled with the possibilities to virtually investigate the effects of different material properties new possibilities are available for an economical and safe way of introducing and using these new materials.

Key words: In-situ cast concrete, lattice girder elements, structural behaviour, experiments, numerical analysis, fibre-reinforced concrete.

INTRODUCTION

In the ongoing research programme at Chalmers University of Technology, a study was made of the structural behaviour of lattice girder elements. The project was initiated by AB Färdig Betong and Thomas Concrete together with Chalmers as a response to the growing demand for improved construction methods for in-situ cast concrete structures. For a concrete building, roughly 40 percent of the total cost of the superstructure can be referred to labour costs, see Löfgren & Gylltoft [1]. More efficient and industrial construction of concrete structures is a necessity for the future competitiveness of concrete and essential if the concrete construction industry is to move forward. Industrialisation may be achieved by using improved materials, high-performance concretes, in combination with effective in-situ cast techniques and new formwork systems such as permanent/integrated forms. Although there is little doubt that structural systems with improved performance could be able to be produced, there are some barriers to this development. When new materials are used and combined the practising engineers need guidelines, methods, and tools that can be used for design and analysis. Moreover, to be able to introduce new materials and structures in an economical and safe way, it is necessary to have a deep understanding of the structural behaviour of the system in question and how this is linked to the material properties and behaviour of the materials.

OVERVIEW AND DESIRED DEVELOPMENT OF THE SYSTEM

The lattice girder system consists of a precast panel with a minimum thickness of 40 mm, a lattice girder and bottom reinforcement, see Figure 1. The elements are cast in a factory, transported to the site, and lifted into place before in-situ casting.

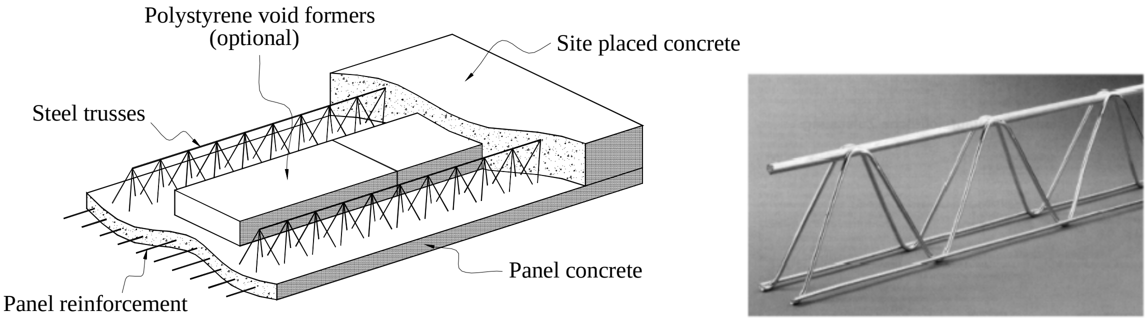

Figure 1. *Characteristics of the lattice girder system, a composite permanent formwork, and a lattice girder truss.*

A natural stage in development is to improve a characteristic performance. In this case this primarily involves stiffness and load resistance during the construction stage. It may also include the weight of the element to simplify transportation and handling of the elements. From the contractor's point of view, there is a desire to increase the spacing of props. This would lead to less congestion and disturbance on site, and minimise the need for temporary works and the associated costs. From the manufacturers' point of view, there is a desire to minimise transportation costs, by reducing the weight and the thickness of the elements. Reduced weight would also be beneficial for the contractor since this could enable the use of a smaller crane.

NUMERICAL SIMULATION

A finite element model was set up in the program DIANA, see TNO [2]. The model is shown in Figure 2. The model was first used to compare the numerical results with results of full-scale tests in order to investigate whether the model was able to simulate the structural behaviour in a reasonable manner, see Figure 3 (a). For more information about the tests and the numerical analysis see Löfgren [3]. The final step in the present study was to investigate the possibilities that fibre reinforcement has to offer, primarily by changing the tension-softening behaviour and the fracture energy, see Figure 3 (b).

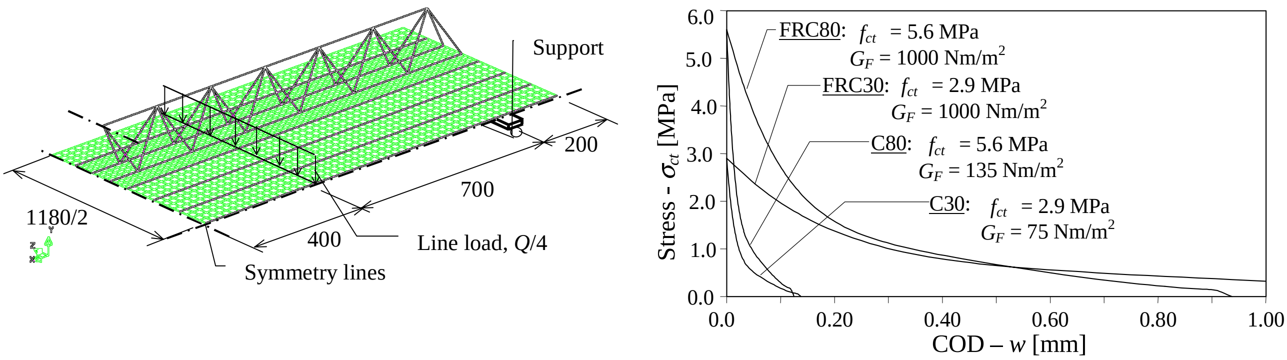

Figure 2. *(a) Finite element model representing a lattice girder element. (b) Tension softening used in the analysis, for different types of concrete C30 and C80 based on material parameters according to CEB-FIP MC90 [4].*

The results of the numerical analysis suggests that the toughness, which an addition of fibres could provide, influences the structural behaviour, both for the serviceability- (limiting deflections) and the ultimate limit state, see Figure 3 (b). The stiffness of the system, after cracking, is increased and it is thus able to carry a larger load at the same deflection; this is more pronounced for the high-strength concrete. Furthermore, the peak load is increased, even though the top chord buckles at the same stress, since the concrete is able to participate in the load-carrying capacity. The crack formation seems to differ between the normal-strength concrete and the high-strength concrete, with fewer cracks forming for the high-strength concrete. The increased modulus of elasticity of the high-strength concrete significantly increases the stiffness of the system. However, when cracks are initiated this results in a rapid degradation of the stiffness, and the top chord now has to carry a larger compressive force in order to balance the bending moment. Furthermore, as cracking is initiated for a rather high load, almost the same as the peak load, the behaviour becomes brittle. The increased toughness seems to be of particular importance for the high-strength concrete where the crack initiation leads to a rapid stiffness reduction.

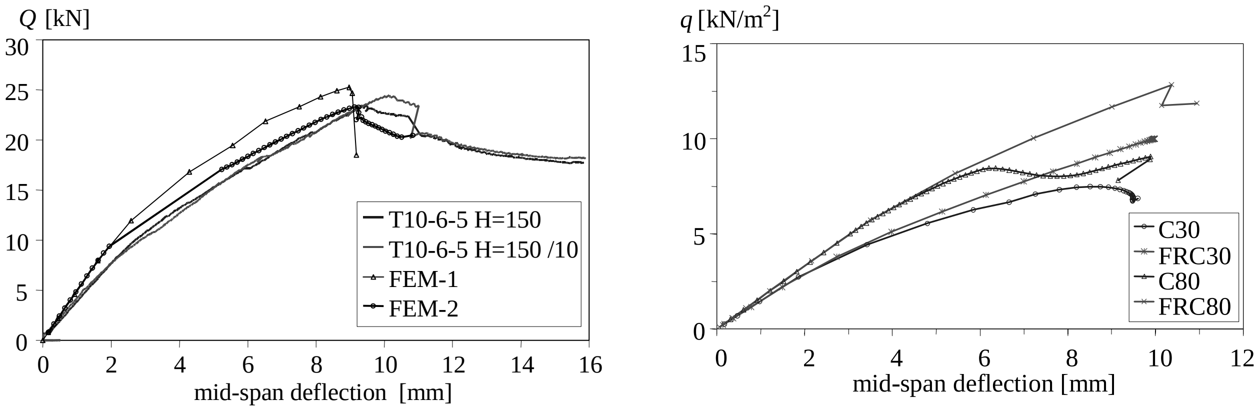

Figure 3. *(a) Comparison of experiments and numerical analysis. (b) Comparison of different materials – normal-strength (C30), high-strength (C80), and two different fibre-reinforced concretes (FRC30 and FRC80).*

CONCLUSIONS

This investigation has shown that with numerical tools it is possible to virtually study the effects of different materials on the structural behaviour of the system. The study was limited to simulating the effect, within certain geometrical configurations, on four types of concrete: normal-strength, high-strength, fibre-reinforced normal-strength, and fibre-reinforced high-strength. The structural behaviour of the lattice girder element is, above all, affected by the geometrical configuration of the lattice girder. However, tension stiffening as well as the tension softening of the concrete have a substantial influence on the structural behaviour. One conclusion is that lattice girder elements could be one interesting application for fibre-reinforced concrete and, with the opportunities that exist today for designing materials, an appropriate mix proportion should not be impossible to develop. Based on a deep understanding of the structural behaviour, the link between structural behaviour and material properties/behaviour can be utilised to optimise the structural performance. Moreover, when the mechanisms behind the structural behaviour have been identified, the design optimisation to achieve the desired performance of the product can be realised by optimising both the geometry and the materials.

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